# CHAPTER 5 - LANDSCAPE CHANGE DESCRIBED BY SELECTED METRICS

'*Quando eu percebi, isso aqui tava tudo mudado*'

## 5.1 - Why study landscape change in Rondônia?

The interest of naturalists and ecologists in landscape spatial patterns is extensive (Urban et al. 1987, Turner et al. *Predicting* 1989). This approach, responsible for an ecological perspective about the geographic space, is today represented by landscape ecology. The term was initially proposed by Troll (1939) and used by Schmithusen (1942) and Neef (1956), among others. The tradition in regional geography and vegetation ecology studies was in the origin of this recent science (Bertrand 1968, Godron et al. 1968, Long 1974, Jurdant et al. 1977). Its historical development was widely reviewed by Naveh (1982) and Naveh and Lieberman (1984).

The concept of landscape was always present in the history of civilization, induced by artistic motivation, as a complementary descriptor on the delimitation of territories. Recently, landscapes became objects of study, analysis, and synthesis, including new perspectives about the distribution of ecological systems. The landscape is no longer considered just 'a portion of the earth surface captured by human eyes' (Amandier 1973). It is now understood as a spatially heterogeneous mosaic (Forman and Godron 1981) to be studied from the reciprocal effects among spatial patterns and ecological processes (Pickett and Cadenasso 1995). Others have emphasized the human dimension underlying landscape outcomes (Naveh and Lieberman 1994). The study of these relations confers a practical dimension to landscape ecology, through the establishment of scientific bases for planning, management, conservation, and development of territories (Leser and Rodd 1991).

Since the expression of such studies is spatially represented, the issue of scale and resolution is central (Allen and Starr 1982, Meentemeyer and Box 1987, Pickett and Candenasso 1995). Recent empirical tests have focused on the role of scale and resolution for understanding relations among patterns and processes of landscape change. Changing spatial resolutions, for instance, may affect our ability to extrapolate information across different scales (Turner and Gardner 1991). Traditionally, many researchers have assumed that ecological processes affecting populations and communities operate at local scales (Dunning et al. 1992). Meanwhile, habitat variations respond to different scales (Wiens 1989), making the problem of spatial dynamics one of the frontiers of ecology (Levin 1992, Kareiva 1994). The current interest in biodiversity, within the landscape context, unites the research on population dynamics and ecological processes (Ricklefs 1987, Norton and Ulanowicz 1992, M. Turner et al. 1995). Perhaps, an important methodological problem for landscape ecological studies may be the difficulty of repeating observations through time and space. For this reason, quantitative approaches, through models of analysis and simulation, still dominate (Sklar and Costanza 1991).

In landscape ecology, the need for studies at multiple scales suggests the use of spatial data analysis (Turner et al. *Predicting* 1989). This has been done through modern approaches to address spatial patterns and ecological processes (Turner et al. *Effects* 1989, Turner 1990, Flamm and Turner 1994, Wickham and Norton 1994). The parallel development of geographic information science (Goodchild 1992) and landscape ecology (Forman and Godron 1986) provides new opportunities for multi-disciplinary studies on ecological modeling of spatial data (Raper and Livingstone 1995). However, the nature of spatial data is diverse and such applications must take the actual nature of the ecological phenomena into account instead of just testing algorithms. Like the 'illusion of objectivity' inherent to analyses of statistical data (Berger and Berry 1988), the analysis of spatial data also includes a variety of pitfalls. However, the need for quantitative methods is an incentive to search for standards. In a world of constant change from global to local scales, it is urgent to overcome the limitations of spatial representations and find better ways to handle their intrinsic problems.

One of the primary steps of spatial analytical initiatives is to identify their underlying assumptions. Frequently, the assumptions are so strong that even the choice of methodological techniques to be used is affected. For example, Anselin (1989) emphasized that the uniqueness of spatial data is expressed by three characteristics. First, it is primarily based on two continuous dimensions (x,y). Second, it presents spatial dependence: 'the propensity for nearby locations to influence each other and to possess similar attributes'. Third, geographical data is distributed over the curved surface of the Earth (from projections to the sphere). The field of geostatistics has followed the assumptions of continuity and spatial dependence (Rossi et al. 1992). It is reasonable to expect such characteristics when dealing with spatial data, until there is a boundary. As human-altered landscapes are full of sharp boundaries (Forman 1997), difficulties have been faced to integrate geostatistics and landscape ecology.

Another relevant issue when dealing with spatial data is that spatial representation can assume multiple forms. Areal data, point data, network data and directional data are the most common ones (Burt and Barber 1996). The purpose of these spatial representations is to mimic a range of phenomena. Thus, examples include land-use/land-cover maps as areal data, vegetation samples as point data, drainage systems as network data, and wind or water flow as directional data.

Several representation techniques have been tested through statistical approaches to allow integration of distinct spatial distributions. Although there are methods to convert data from different spatial representations (e.g., point data into areal data and vice-versa), the procedure is not always recommended. Recently, development efforts are willing to integrate this distinct group of techniques in a more friendly way to handle spatial data (Goodchild et al. 1992, Burrough and Frank 1995). Geostatistics techniques (Issaks and Srivastava 1989), spatial analysis (Burrough 1990, Baker and Cai 1992, Fotheringham and Rogerson 1995, McGarigal and Marks 1995), and GIS capabilities (Burrough and McDonnell 1998, DeMers 2000) have provided new opportunities to explore spatial- and scale-related matters (Withers and Meenteneyer 1999).

The potential of such an integrative approach to handle spatial phenomena for the study of landscapes is promising. However, this functionality is still not implemented in a friendly way that allows a reasonable manipulation of different spatial data representations through complementary techniques. Also, although the integration has been frequently suggested, it is rare to see studies in landscape ecology dealing with point data, for example. This is probably related to the rationale behind the study of landscape structure, based on the concepts of matrix, patch, and corridor (Forman and Godron 1986, Forman 1997). Landscape mosaics imply discreteness of elements and the existence of clear boundaries between neighboring patches (Hansson et al. 1995). Thus, spatial statistics has been used to describe the degree of spatial autocorrelation or spatial dependency between values of a variable that has been sampled at various geographic coordinates, while landscape metrics characterize the geometric and spatial properties of a mosaic of patches (Fortin 1999).

The applicability of these concepts to spatially explicit ecological studies is clear. In a world where human-altered landscapes are increasingly created, processes of disturbance need to be spatially quantified and understood. Disturbance can be defined as any relatively discrete event in time that disrupts the ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Pickett and White, 1985). The propagation of disturbance in heterogeneous landscapes depends on the structure of the landscape, as well as on the intensity and frequency of disturbances. M. Turner et al. (1995) highlighted the importance of new conceptual approaches when studying disturbance within landscapes. For instance, a broader view of the equilibrium concept should expect a return to normal dynamics rather than to an artificial 'undisturbed' state. Moreover, as disturbed sites recover deterministically through succession, stability must be assessed through multi-temporal and -spatial approaches, taking into account the scale-dependent nature of concepts of landscape equilibrium (M. Turner et al. 1993).

When studied through the landscape ecology approach, the structure of 'disturbance landscapes' is controlled by characteristics of the disturbance regimes, including the distribution of disturbance sizes and intervals, and the rotation time. In this case, the structure of mosaics of disturbance patches (e.g., patch size and shape) is an important parameter to assess landscape structure (Forman and Godron 1981). Both the number and size of patch births (i.e., patch turnover) govern the response of landscapes to changing disturbance regimes (Baker 1995).

Several methods based on the concept of landscape structure have been developed to address processes of disturbance within landscapes. Landscape metrics have been widely used for this purpose (Baker and Cai 1992). The integration of spatial data in GIS has improved this approach (Haines-Young et al. 1996, Forman 1997, Frohn 1998). Using GIS and landscape metrics to relate disturbance and spatial heterogeneity allows the study of environmental composition and configuration at scales broader than the community or ecosystem (Sample 1994). There are metrics related to landscape composition, referring to features associated with the presence and amount of each patch type within the landscape but without being spatially explicit. Others are related to landscape configuration, referring to the physical distribution or spatial character of patches within the landscape (Burrough 1981, Mandelbrot 1983, McGarigal and Marks 1995).

Perhaps, one of the most frequent examples of landscape disturbance in the tropics is derived from LULC change, particularly forest fragmentation. The process occurs when forested areas are progressively subdivided into smaller and more isolated forest fragments, mainly as a result of human land-use activities. Landscape heterogeneity can either increase or decrease, depending on the parameter and spatial scale examined (Krummel et al. 1987). In general, the disturbed landscape has more small forest patches and fewer large, matrix patches than the intact landscape (Lovejoy et al. 1986, Mladenoff et al. 1993, Malcolm 1994, Lovejoy 1997).

Taking this assertion as a hypothesis, this research examines landscape structure in Rondônia through derived LULC classifications. Machadinho and Anari are analyzed in terms of their composition and configuration in a multi-temporal basis. Results for both sites are compared, trends are described, and methodological issues are discussed.

## 5.2 - Conceptual and methodological approach

The ecological concept of landscape has been extensively discussed. More than trying to coin an ultimate meaning for the term, this research addresses landscape as an interacting mosaic of patches or ecosystems relevant to the phenomenon under consideration (McGarigal and Marks 1995). Building on findings described in the last chapter, LULC change is used as a proxy for landscape transformation to understand how Machadinho and Anari have evolved from little disturbed environments covered by forests to a fragmented mosaic of human-induced agroecosystems.

Three other characteristics define a landscape: its elements are under the influence of the same broad climate, similar geomorphology, and similar disturbances. In addition, landscape structure is defined by the spatial relationships among ecosystems. Landscape function is related to the interactions among the spatial elements (i.e., flows of energy, materials, and species). Landscape change is the alteration in the structure and function of the ecological mosaic over time (Forman and Godron 1986). This chapter does not focus on the function of landscapes or patch mosaics within the study area, although its findings may be used for this purpose. It rather concentrates on the structure of those landscapes and how they have changed since the settlements were implemented in Rondônia. Additionally, this research is not an empirical test about the behavior of metrics measuring landscape structure, but a comparison between agroecological processes and spatial patterns in Machadinho and Anari through the use of quantitative methods. LULC is the most important variable affecting structure, function, and change within landscapes in the study area. Other variables, such as topography and soils were assumed to be similar at the scale of analysis.

After Turner et al. (*Predicting* 1989) and Silbernagel (1997), the following definitions are used. Scale is the temporal or spatial dimension of an object or process, characterized by both grain and extent. Resolution is the precision of measurement (grain size, if spatial). Grain is the finest level of spatial resolution possible with a given data set (pixel size for raster data). Extent is the size of the study area or the duration of time under consideration. These parameters were kept under control to allow the comparative analysis of landscape structure and change in Machadinho and Anari. As presented in Chapter 4, LULC was classified through the lens of Landsat TM images and both settlements are in the same scene. Thus, grain size is equivalent. The extent of each landscape was defined by the settlement boundary, as also mentioned before. The goal of this study is to compare the two different designs of colonization in terms of landscape structure and change: fishbone design encompassing just private properties versus topography-based design including private properties and communal reserves. The next section describes the methods of analysis and data used.

Last but not least, three concepts characterizing landscape structure deserve attention: patch, corridor, and matrix. Their definitions were borrowed from Forman and Godron (1986). Patch is a ‘nonlinear surface area differing in appearance from its surroundings’ and created by mechanisms involving disturbance, environmental heterogeneity, and human activity. Within the study area, the mosaic of patches evolves and changes according to two major processes: land occupation and secondary succession. Land occupation can generate 'disturbance patches,' for example, by logging or burning. It also creates 'introduced patches,' such as pasture, agriculture, bareland, and built-up land such as urban areas and roads. Succession gives place to 'regenerated patches' according to different stages of vegetation regrowth. Forest and water are what is left from land occupation and succession. The former represents the original landscape matrix and tends to evolve to 'remnant patches' within the settlements. Water is represented by natural lotic environments (i.e., rivers and streams) or manmade lentic environments (i.e., lakes and water ponds). The latter are 'environmental resource patches' but could also be classified as 'disturbance patches,' as they were artificially created. The former are best understood as landscape corridors because of their shape and function.

Corridors are 'narrow strips of land which differ from the matrix on either side'. Roads and watercourses represent landscape corridors within the study area. Roads are 'disturbance corridors' and watercourses are 'environmental resource corridors.' This research does not emphasize the study of landscape corridors, particularly because they represent small portions within the landscapes. However, further studies should investigate the role of corridors as functional elements interfering in LULC change processes.

Matrix is the 'most extensive and most connected landscape element type, and therefore plays the dominant role in the landscape' functioning. Forman and Godron (1986) established three criteria to define a matrix: relative area of landscape element types, level of connectivity present, and degree of control over landscape dynamics. The element type within the landscape with higher values for these three parameters would be the landscape matrix. In the study area, forest could be assumed to be the matrix. It was for sure in early stages of colonization, when a large contiguous forested landscape dominated Machadinho and Anari. After landscape change following colonization and land clearing, forest still has the largest areal extent, but other landscape elements tend to take its place (i.e., succession and production areas, for example). For comparative purposes through this multi-temporal study, forest was treated as another landscape element type composed of patches, instead of being designated as the landscape matrix. Operationally, this decision did not affect measurements of landscape structure although the function of the forest element within the landscape boundaries may have changed. On the other hand, assigning forest as a patch type (class) allowed a useful comparison between processes of fragmentation between the study sites.

Landscape ecologists have recently pointed out the need of new developments and standardization for quantitative analysis of landscapes (Wiens and Moss 1999). With this study in Rondônia, my goal is to contribute to the rain forest fragmentation debate through a better understanding of spatial pattern and process by using a set of comparable metrics.

## 5.3 - Data and methods

A multi-temporal approach was used to characterize landscape change in Machadinho and Anari in 1988, 1994, and 1998. LULC classifications were similarly recoded for both settlements to facilitate interpretation of landscape pattern and change

(Table 25). The recoded classes were based on the main processes occurring in the study area and affecting landscape transformation, that is forest fragmentation through deforestation, vegetation recovery through succession, and land occupation through pasture and agriculture conversion.

The delimitation of landscape boundaries for calculation of metrics is central, as discussed later in section 5.5.2. In Chapter 4, the largest settlement area with available satellite data was used for the calculation of LULC percentages. In this chapter, the settlement boundaries are still assigned as landscape limits. However, for Anari the boundary of the smaller subset (1994) was used to clip the classifications for other dates. The procedure left 11% of the Anari settlement out of the analysis, but allowed consistency during calculation and comparison of metrics. For Machadinho, metrics were calculated for the entire settlement, including and excluding the communal reserves. For this latter case, the reserves were considered as background with no class value.

Metrics were computed at three levels of analysis, that is landscape, class, and patch (McGarigal and Marks 1995). Each settlement was assigned as one landscape. Thus, the study differentiates the landscape of Anari with its orthogonal design of roads and parcels, and the landscape of Machadinho following topographic features. Class is the patch type (i.e., forest, succession, production land, or others). Patch was already defined in the section above and operationally corresponds to each polygon of the vector coverages. Areas smaller than 900 $m^2$ were not computed to keep consistency with the pixel size of satellite images used for LULC classifications (30 x 30 m). By the same token, the buffer area for core metrics calculations was 90 m wide. This width was chosen based on various studies about edge effects on tropical forest remnants in the Amazon (Laurance and Bierregaard 1997).

Several metrics were computed at the landscape, class, and patch levels of analysis. Table 26 lists these metrics and their respective acronyms. At the patch level, additional descriptive statistics were computed for the population of patches. Tables and graphic outputs allowed comparisons between the two landscape patterns and changing processes within the ten-year period (1988-1998). Appendix 2 describes the metrics used for each level of analysis. Formulas and descriptions were compiled from McGarigal and Marks (1995).

**5.4 - Spatial pattern and process in Machadinho and Anari: metrics and trends**

The following sections present the results for landscape, class, and patch metrics.

**5.4.1 - Landscape: a broad comparison between the study sites**

Landscape metrics should be considered with caution, as they average values obtained for patches and classes within the landscape. However, when comparing two distinct architectural designs of colonization in the Amazon on a multi-temporal basis, an overview of these metrics can provide a first indication about landscape structure and change. The following paragraphs comment the results presented in Table 27.

The Largest Patch Index (LPI) quantifies landscape composition through the percentage of total landscape area encompassed by the largest patch. LPI has been widely used as an indicator of landscape fragmentation. LPI decreases in both settlements as deforested areas expand through time. In Anari, LPI decreases threefold, while in

Machadinho it decreases less than twofold. However, when excluding the communal reserves from Machadinho's design, LPI decreases abruptly to 2.6% of the landscape.

Patch density, patch size, and variability metrics also serve as indicators of fragmentation processes within landscapes. Patch density (PD) is greater in Machadinho in all dates, but increases at a lower rate than in Anari. Mean Patch Size (MPS) is larger in Anari, but much more stable in Machadinho through time. As both PD and MPS are functions of the number of patches and total landscape area, these results are somewhat redundant and indeed show the same process. MPS is more informative when interpreted together with a measurement of dispersion. Patch Size Standard Deviation (PSSD) and Patch Size Coefficient of Variation (PSCV) are variability metrics and indicate aspects related to landscape heterogeneity. Thus, landscapes with greater PSSD and PSCV are more heterogeneous and landscapes with lower PSSD and PSCV are more uniform. For the three cases being analyzed, PSSD and PSCV tend to decrease over time and particularly at a higher rate in Machadinho when excluding the reserves. This tendency is largely influenced by values for PSSD and PSCV for classes, as will be shown below.

Another group of indicators of landscape fragmentation is represented by edge metrics. Edge Density (ED) was chosen for comparative purposes between Machadinho and Anari because Total Edge (TE) is directly affected by the size of landscapes under analysis. ED is a measurement of landscape configuration with applications to the study of edge effects. Values for ED in Machadinho, including reserves, and in Anari are roughly similar in all dates. When excluding the reserves, ED in Machadinho is much greater in all dates.

Shape metrics are as important as patch size metrics for the understanding of landscape configuration (Milne 1988). Two shape metrics were used for landscapes within the study area, both derived from comparisons to a circular shape at the patch level (Appendix 2). The Landscape Shape Index (LSI) increases over time in all cases, although it has lower values in Anari and higher values in Machadinho when excluding reserves. In Machadinho, the Area Weighted Mean Shape Index (AWMSI) decreases from 1988 to 1998. It starts with the same value with or without reserves and decreases more abruptly when reserves are not included for the calculations. In Anari, AWMSI increases from 1988 to 1994 and is stable from 1994 to 1998.

Core area was defined as the area within a patch beyond the distance of 90 m from its edge. Also important for the study of edge effects, core area metrics were selected for the research in Rondônia. These metrics indicate both aspects related to composition and configuration. For landscapes, the Total Core Area Index (TCAI) was used. It quantifies core area for the entire landscape as a percentage of total landscape area. TCAI decreases 20% in Machadinho over time. When excluding reserves, TCAI decreases 27% during the period of study, as it does in Anari.

Diversity metrics quantify landscape composition by measuring richness and evenness of patch types. Richness refers to the number of patch types and evenness refers to the distribution of area among different types. The Modified Simpson's Diversity Index (MSIDI) was used to reflect differences in patch richness over time. The Modified Simpson's Evenness Index (MSIEI) quantified evenness among the landscapes. Although MSIDI and MISEI increase approximately threefold for all landscapes under analysis over time, Machadinho is less diverse and less even in all dates. When excluding reserves from the analysis, diversity metrics in Machadinho are closer to values observed in Anari.

The nterspersion and Juxtaposition Index (IJI) measures how intermixed patch types are within a landscape and, therefore, are related to configuration. IJI is calculated in percentage units and approaches 100% when all classes are equally adjacent to all other classes. Machadinho shows higher IJI values in all dates, followed by the less interspersed landscapes of Anari and Machadinho without reserves. An interesting finding is a higher IJI value for all cases in 1994. The next section presents the results for metrics calculated at the class level and provides a more detailed perspective about pattern and processes within landscapes in Machadinho and Anari.

### 5.4.2 - Class: understanding LULC change through spatial metrics

Selected metrics were computed for classes within Machadinho and Anari landscapes. Results for forest are particularly emphasized in this section, as they play an important role in defining landscape structure and fragmentation within the study area. Percentage of Landscape (PLAND) and Largest Patch Index (LPI) provide results in terms of percentage of total landscape covered by all patches of a class and by the largest patch of a class, respectively (Appendix 2). As pointed out in Chapter 4, PLAND of forest in Machadinho dropped from 88.4% in 1988 to 65.7% in 1998, while in Anari these values were 86.8% and 52.9%, respectively. When excluding the communal reserves from the analysis, Machadinho shows the same rate of deforestation as Anari. Areas in succession increased about 11.9% in Machadinho, 16.7% if excluding the reserves, and 15.4% in Anari during the period of study. For production areas, these figures were 10.7%, 15.4%, and 18.3%, respectively. PLAND for other areas (water and built-up land) stayed stable over time (Table 28). These trajectories were also discussed in Chapter 4 and complemented by property-based data analysis, although a more disaggregated classification system was used at that point.

The examination of LPI for each class allows a better understanding about the behavior of this metric than when analyzed for the entire landscape (Table 29). LPI for forest decreases with time down to 10.7% in Machadinho, 4.5% in Anari, and only 2.6% in Machadinho without reserves. Anari shows consistently higher values of LPI for succession and production areas in all dates.

Patch density, patch size, and variability metrics were also calculated for landscape classes (Tables 30 to 33). Patch Density (PD) of forest increases more than 2.5 times in Anari during the period of study. In Machadinho, it increases at a much lower rate. Higher values of PD are observed for forest in Machadinho when excluding reserves. PD of areas in succession increases at a similar rate for all cases although its values are higher in Machadinho, particularly when excluding reserves. In Machadinho, PD of areas in production decreases from 1988 to 1994 and increases from 1994 to 1998. In Anari, it just increases over time (Table 30).

In Machadinho, Mean Patch Size (MPS) of forest fragments dropped from 319.0 ha (n=592) in 1988, to 219.1 ha (n=741) in 1994, and to 167.4 ha (n=838) in 1998. In Anari, these metrics were 556.4 ha (n=170) in 1988, 224.9 ha (n=332) in 1994, and 126.7 ha (n=455) in 1998. In Machadinho without reserves, MPS of forest is considerably smaller in all dates (Table 31). Values of MPS for succession areas, production areas, and other features are unaffected by the exclusion of forest reserves. MPS of succession areas in both landscapes are similar in 1988 and 1994, but larger in Anari in 1998. MPS of areas in production are always larger in Anari.

Patch Size Standard Deviation (PSSD) and Patch Size Coefficient of Variation (PSCV) were also computed for landscape classes (Tables 32 and 33). In succession areas, production areas, and other features, PSSD and PSCV values are also unaffected by the exclusion of forest reserves. PSSD of forest decreases in all cases. In Machadinho, the exclusion of reserves from the analysis causes an abrupt drop in PSSD values for forest. PSSD of succession areas is greater in Anari in 1998, while PSSD of production areas is always greater in all dates (Table 32). PSCV of forest in Machadinho decreases slowly over time but rapidly if reserves are excluded. In Anari, PSCV of forest increases from 1988 to 1998 (Table 33).

Results for Edge Density (ED) of forest are roughly similar for all dates in Machadinho and Anari. When excluding the reserves in Machadinho, PD of forest is greater. Similar trends were found for ED of succession and production classes. In all cases, PD increases over time (Table 34).

Landscape Shape Index (LSI) and Area Weighted Mean Shape Index (AWMSI) were also computed for all classes. As done for landscapes, these metrics quantify the amount of edge present in a class relative to what would be present in a class of the same size but with a circular shape. In other terms, these metrics provide a relative measurement of shape complexity. The particularity about AWMSI is that larger patches are weighted more heavily than smaller patches in calculating the average patch shape (Appendix 2). LSI increased for all classes in Machadinho and Anari over time. LSI of forest increased 1.5 times in Machadinho and twofold in Anari. However, values in Anari are lower than in Machadinho in all dates. The highest LSI values for forest were found for Machadinho without the reserves. LSI results for succession, production, and other features were unaffected in Machadinho when excluding reserves from the analysis. In general, Machadinho has higher values of LSI for these classes, but both landscapes present the similar ascendant trend (Table 35).

AWMSI results reveal other interesting findings (Table 36). AWMSI of forest shows opposite trends within the two landscapes, decreasing in Machadinho and increasing in Anari over time. When Machadinho reserves are excluded, AWMSI also decreases, but at a higher rate than when the landscape is complete. AWMSI of succession areas increases similarly in both landscapes. Production areas otherwise have higher AWMSI values in Anari in all dates. AWMSI results for other features (water and built-up land) are notably stable and higher in Anari, while they increase in Machadinho during the period of study.

Opposite trends were found for the Mean Core Area Index (MCAI) of forest. It increases in Machadinho and decreases in Anari over time. MCAI of succession and production areas increases in all cases during the period of study and is always higher in Anari (Table 37).

The last metric calculated for classes within Machadinho and Anari landscapes was the Interspersion and Juxtaposition Index (IJI) (Table 38). This metric defines how class patches are located in relation to other patches of the same class and to patches of other classes within the landscape. IJI of forest is greater in Machadinho in all dates, followed by Anari and Machadinho without reserves. In all cases, values of IJI of forest are similar in 1988 and 1998, peaking in 1994. IJI of succession areas decreases 4% in

Machadinho, 3.2% in Machadinho without the reserves, and 9.2% in Anari. IJI of production areas also increase in 1994 in all cases, decreasing in 1998 but at a higher level than in 1988. A similar trend occurs for other features (water and built-up land). The next section describes the results found for patch metrics.

### 5.4.3 - Patch: polygon-based descriptive statistics

Patch-based metrics were also computed for Machadinho and Anari landscapes. The paragraphs below present results for area of patches (AREA), perimeter of patches (PERIM), shape index of patches (SHAPE), and fractal dimension of patches (FRACT) (Appendix 2; Figures 71–82). Results for forest, succession, and production patches are emphasized. Patches of other features (i.e., water and infrastructure features including roads and urban areas) show little variation over time and are not discussed.

For the patch-based analysis, it is important to remember that the box within boxplots represents the interquartile range and contains 50% of all values. The line crossing the box is the median. Whiskers represent the highest and lowest values, excluding outliers. Unfortunately, for the sake of producing readable and comparable graphs for all dates and cases of study, extremes and outliers were hidden from the output. This weakens the analysis for particular questions but allows a better picture of the majority of values within the statistical population (Ott 1993).

Values for area of patches are presented in Figures 71, 72, and 73. The interquartile range for patches of forest increases in Machadinho over time, either including or excluding reserves. In Anari, this interval is more stable through time although greater in 1988. The distribution of values for area of succession and production patches is similar in both cases analyzed for Machadinho in all dates, with the interquartile ranges for both classes tending to increase over time. In Anari, the distribution of successional areas is also similar to Machadinho in 1988 and 1994. In 1998, the interquartile range and highest value are slightly greater. The range and highest value of production areas in Anari are slightly greater than in Machadinho in 1988, distinctively greater in 1994, and slightly smaller in 1998.

The interquartile range for perimeter of forest patches increases in Machadinho during the period of study. In Anari, it decreases from 1988 to 1994 and slightly increases in 1998. The range is obviously greater in Anari in 1988, similar but with higher median in 1994, and smaller but with similar median in 1998. Including or excluding reserves do not affect results for perimeter of succession or production patches in Machadinho. In both cases, the range increases slightly in 1994 and remains stable in 1998. In Anari, the median of perimeter of succession patches is often higher than in Machadinho, while the interquartile range is greater only in 1998. For production areas, the median and range are greater in Anari than in Machadinho in 1988 and 1994. In 1998, the range is smaller in Anari and the median is equivalent in both settlements (Figures 74, 75, and 76).

Some points deserve consideration for the shape index and fractal dimension, as shown in figures 77 to 82. The interquartile range of the shape index for forest patches is slightly greater in Machadinho when excluding reserves from the analysis. The presence of reserves does not affect values for succession and production patches. In Anari, the range for forest is greater than in Machadinho in 1988, but smaller in 1994 and 1998. The median is also smaller in 1998. Shape index for succession patches in Anari has similar ranges and medians as Machadinho in all dates. For production areas, the shape index in

Anari is similar to Machadinho in 1988 and 1994. In 1998, its range and median are smaller.

Fractal dimension measures shape complexity for each patch within the landscape. It ranges from 1 to 2, with 1 meaning Euclidian geometric shapes such as circles and squares, and 2 meaning a very complex patch shape. In Machadinho, the median fractal dimension of forest patches decreases as its range increases over time. When excluding reserves, the trend is similar, although the upper quartile and highest values are greater in 1998. In Anari, the median for forest patches decreases from 1988 to 1994 but increases slightly in 1998. The interquartile range also decreases from 1988 to 1994 and remains stable in 1998. Fractal dimension of patches of succession and production areas are unaffected when excluding reserves from the analysis in Machadinho. The median slightly increases for succession areas from 1988 to 1994 and stays stable in 1998. In Anari, values for fractal dimension of succession patches are very similar for all dates. The median and range of fractal dimension of production patches decreases in 1994 in Machadinho and remains equivalent in 1998. A similar trend was found for Anari although the median values are lower.

## 5.5 - Landscape transformation in Machadinho and Anari

### 5.5.1 - Metrics and meanings

This chapter presents results for landscape, class, and patch metrics, in a multi-temporal approach, for two distinct settlement designs in Rondônia, Brazilian Amazon. Perhaps, the most intuitive analysis of metrics occurs at the class level. Landscape metrics average values of all classes and can lead to misleading conclusions if not analyzed with caution. However, when comparing two landscapes of distinct structure, such as Machadinho and Anari, landscape metrics provide important elements for a description about the general pattern within the settlements. Patch metrics are too disaggregated and can be more useful when analyzing single patches for specific purposes (e.g., habitat studies, reserves delimitation, edge effects, and so on). The importance of patch metrics is mainly related to their role in providing the basis for class- and landscape-level calculations, as depicted by the formulas for these latter metrics (Appendix 2). However, the analysis of distribution of values for specific patch metrics can also contribute to a better understanding about the spatial pattern of landscapes, as patches are the primary elements defining landscape structure. When averaged to the class level, specific patterns within the landscape become clearer, particularly when analyzing LULC change as the most important process leading to landscape transformation.

Other techniques could be used to overcome the limits of this research. A promising study would be to measure the importance of specific groups of patches to processes causing changes in landscape pattern. In the case of roads and watercourses, for example, analysis of connectivity instead of patch distribution would be more appropriate since the design of these corridors ultimately affects landscape patterns and processes of change, as indicated by the analysis of buffers around roads in Chapter 4. Another empirical exercise would be to fill the reserves in Machadinho with a similar pattern found in property areas and simulate the inclusion of permanent reserves within the Anari landscape to test the actual contribution of reserves and architectural design to landscape fragmentation processes. Until these studies are carried out, the paragraphs below discuss the results produced so far, as a contribution to rethinking settlement design in the Amazon.

Results for Percentage of Land (PLAND) are redundant with the ones presented in Table 14, but in this chapter they are aggregated for the recoded classes (i.e., forest, succession, production, and others). Slight differences between these numbers and results presented in Chapter 4 are due to the use of an adjusted boundary for Anari when calculating landscape metrics.[2] The classes used for this research have distinct functions within the landscapes. Further studies may be more specific about their role in flows of materials, energy, and species within landscape elements. PLAND is a very useful metric when comparing same classes between landscapes of different sizes, such as Machadinho and Anari. It is not inappropriate to reaffirm the importance of communal reserves in maintaining a higher percentage of forest cover in Machadinho. Without them, the rate of deforestation becomes similar in both landscapes (Table 28).

The Largest Patch Index (LPI) is one of the most effective metrics measuring landscape fragmentation (Dale 2001). At the landscape level, LPI decreases in all cases, but more abruptly in Machadinho without reserves and Anari (Table 39). This result is actually reflecting what happened to forest class, which shows an equivalent trend (Table 29). The relatively large size of the Aquariquara Reserve in Machadinho is affecting LPI results positively for this landscape. Certainly, the reserve itself and contiguous private forest areas make up the LPI value for forest in Machadinho. Interestingly, because of this communal reserve, this metric tends to remain stable in Machadinho, while it keeps

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[2] As explained before, the adjusted boundary was used to maintain consistency during the multi-temporal comparison in Anari, as 11% of the landscape had no data available for 1988 and 1994.

decreasing in Anari.[3] This has significant ecological implications, as some species need a single large patch as their primary habitat for maintenance and reproduction (Burkey 1989). LPI values for succession, production, and other features have relatively less importance because their largest patches are too small in comparison with the landscape's extent. However, the higher values of LPI for succession and production areas in Anari indicate that land aggregation (for pasture conversion, for example) and land speculation (through relative abandonment) is more current in the fishbone scheme.

Patch density, patch size, and patch variability metrics are other important quantitative measurements to assess landscape transformation and fragmentation because the total amount of energy and nutrients in a patch is proportional to its area (Forman and Godron 1986). The consequences of these matters to species composition and abundance within the landscape are clear. As pointed out by the island biogeographic theory, species diversity or richness is related directly to an island's area, its isolation, and its age (MacArthur and Wilson 1967). Patch size can stand for an island's area for analyses of species habitat (Harris 1984). It is out of the scope of this chapter to discuss the effects of patch size and variability on species. But it is important to mention that the study of landscape structure can effectively contribute to the understanding of occurrence and distribution of organisms (Ricklefs 1987).

Within the study area, results for Patch Density (PD) have to be considered with caution. Although higher in Machadinho at the landscape level (Table 27), this finding reflects the fragmentation of succession and production areas more than of forest stands. This is corroborated by the results of PD at the class level, which are more informative

[3] The largest forest patch in Machadinho has 22,892 ha. The Aquariquara Reserve has 18,100 ha (Table 16). As soon as the areas contiguous to the reserve are cleared, the reserve will be the largest patch itself, stabilizing the LPI at 8.5%.

(Table 30). Production fields and succession areas in Machadinho are smaller and more numerous, increasing PD despite the lower level of fragmentation of forests within this landscape. When excluding reserves from the analysis, values of PD of forest in Machadinho are higher because the large patches of forest are not being considered in the calculation. Results also indicate trends in rates of forest fragmentation. PD of forest increased more than 2.5 times in Anari during the period of study, indicating a faster process of forest fragmentation (Table 40). PD is ultimately measuring landscape and class heterogeneity, providing important quantitative information for land zoning and management initiatives.

Mean Patch Size (MPS) is derived from patch-based area metrics and also indicates fragmentation. The first important finding within all cases under analysis is that MPS averaged for the entire landscape decreases over time (Table 39). Also, landscape MPS is lower in Machadinho, but decreases at a faster rate in Anari. To better understand these rates of fragmentation and which landscape elements are contributing to the process, analyses at the class level are more helpful. In general, MPS decreases for forest and increases for all other classes (Table 40). Moreover, a lower pace of forest fragmentation is indicated for Machadinho when compared to Anari. Although MPS of forest was smaller in Machadinho in 1988, it ended up larger after a decade of landscape transformation. This occurred because MPS of forest decreased 1.9 times in Machadinho and 4.4 times in Anari during the period of study! The fishbone scheme tends to show lower levels of fragmentation during the early stages of colonization due to the large elongated patches of forest located between roads. However, when forest clearing advances, these patches are subdivided into several smaller patches. In Machadinho, communal forest reserves combined with private property forests produced a more stable landscape. If the reserves are excluded, MPS of forest drops abruptly, suggesting a much more fragmented class than even the fishbone design. Obviously, the exclusion of reserves in Machadinho was just an empirical exercise. Nevertheless, the results offer an alert for further initiatives trying distinct settlement designs in the Amazon. MPS of successional vegetation and cropland are always greater in Anari through time. These trends are affected by the increase in pasture areas and associated secondary vegetation within the fishbone settlement. Results for MPS of succession, production, and other areas are unaffected when excluding reserves in Machadinho because these three classes are barely absent within the reserves. Conversely, results for patch-based and class-based area metrics for forest are always affected by the exclusion of reserves, indicating the importance of their patches for the statistical population and distribution of forest class within Machadinho's landscape (Figures 71, 72, and 73).

As an average, MPS is sensitive to extreme values. Thus, its results are better interpreted when analyzed together with measurements of dispersion. The behavior of Patch Size Standard Deviation (PSSD) and Patch Size Coefficient of Variation (PSCV) follows the trends observed for MPS. In general, these dispersion metrics decrease as MPS for forest decreases and increase as MPS for the other classes increases over time (Tables 39 and 40). In other terms, the variability in patch size of forest and landscapes as a whole is decreasing, making the distribution of these metrics more uniform. The only exception refers to PSCV of forest. As it is calculated as a percentage of MPS, it increases in Anari, reflecting a higher relative variability in size of forest patches within the fishbone landscape in 1998, even with a lower absolute variability measured by

PSSD. On the other hand, PSSD and PSCV of production and succession classes increase over time, indicating that these areas are becoming larger, with different sizes (Tables 27, 32 and 33).

The next two groups of metrics (i.e., edge metrics and shape metrics) have important applications for the study of edge effects, which certainly affect the dispersal and foraging of organisms (Ranney et al. 1981, Laurance and Bierregaard 1997). Edge effects are important ecological phenomena and particularly useful for the study of rain forest fragments (Lovejoy et al. 1986, Malcolm 1994, Kapos et al. 1997, Laurance 1997). The amount of edge and the shape of patches dictate the interactions between distinct patch types and, consequently, the flow of species throughout the landscape. In this sense, a large but elongated patch, such as the strips of forest between roads in Anari, could become completely edge habitat. More than explore scenarios about edge effects occurring within the landscapes of Machadinho and Anari, this research provides a preliminary analysis of edges and shapes as a basis for further studies regarding ecotones and transitions among patch types. Comparative studies of species diversity and abundance in Machadinho and Anari, for instance, could offer new elements for discussion about settlement design.

The similarity found in Edge Density (ED) for classes in Machadinho and Anari suggests that fragmentation is taking place within both landscapes (Tables 34 and 40). In general, ED is increasing for all classes as the process of occupation and LULC change advances. The abrupt increase in ED when excluding reserves in Machadinho should not guide us to misleading conclusions. In this case, the results are affected by the reserves' edges, considered as background for calculations. Further studies about edges within those landscapes should explore the role of contrasts between different patch types. The absence of results for edge contrast metrics minimized the potential of indicators to analyze ecotones. Depending on the land-cover class adjacent to forest patches, for example, different effects may be observed in terms of ecological processes. If forest patches border open vegetation, such as production areas, this fragment may become more susceptible to disturbances in its structure and composition. Conversely, if forest patches are adjacent to succession areas, secondary regrowth may be accelerated. Investigating these relationships would bring a better understanding about the functional significance of each patch type. Such inferences go beyond the purposes of this study, but the exploratory results obtained for edge contrast metrics justify the use of these quantitative approaches in further ecological analyses within Amazonian landscapes under processes of LULC change.

Edge contrast and nearest-neighbor metrics were not calculated due to the computer intensity when processing large and complex data sets such as those used for this research. However, exploratory runs for different dates and subsets confirmed what was expected. Edge contrast metrics measure the degree of contrast between a patch and its neighbors by assigning different weights to classes within the landscape. Nearest-neighbor metrics reflect configuration by measuring the distance between nearest patches of the same class, based on edge-to-edge distance. In other terms, they indicate the degree of isolation of patches within the landscape. The following three metrics were used during this exploratory approach (McGarigal and Marks 1995). In general, Contrast Weighted Edge Density (CWED) tends to increase and Mean Edge Contrast Index (MECI) tends to decrease within Machadinho and Anari landscapes over time. Mean

Nearest Neighbor (MNN) also tends to decrease, as these landscapes become more fragmented. The exploratory analysis of edge contrast and nearest-neighbor metrics at the class level indicated similar behavior for both landscapes, as found for landscape metrics. Although the magnitude of each metric for all dates was not computed, some general trends can be mentioned. CWED tends to increase for all classes while MECI tends to decrease, mainly for forest. Mean Nearest Neighbor (MNN) increases for forest and decreases for succession and production areas, as expected for an ecological process where a pristine landscape matrix is progressively subdivided into more isolated remnant fragments.

Shape metrics are also related to edge effects, as patch shape and size dictate perimeter extent and edge with neighbor patches. These perimeter-area relations are intricate to quantify concisely in a metric and often are difficult to interpret (McGarigal and Marks 1995). Patch perimeter distribution was represented in Figures 74, 75, and 76. Perhaps, the most important finding was that perimeter for forest patches in Anari shows a similar pattern in all dates, while in Machadinho it increases over time. The results obtained for the computed shape metrics show relevance related to some particular trends. Landscape Shape Index (LSI) increases over time for all classes and landscapes due to the formation of more irregular shapes (Tables 39 and 40). Values are higher for Machadinho because it has a more complex design. When excluding the reserves, these values are even higher for the same reason explained above for Edge Density (Tables 27 and 35). By the same token, lower LSI values in Anari indicate a lower complexity in patch shape within this landscape. When analyzing these results, it is important to consider that LSI is not measuring shape morphology. In this sense, a large elongated patch could have the same LSI value as a smaller convoluted patch. What LSI is in fact indicating is that the configuration of classes and landscape in Anari is less complex because its design is based on an orthogonal road network. In Machadinho, the design based on topography produces a more complex outcome in landscape shape structure.

When weighted by areas of patches, not just the magnitude but also the trends of shape metrics are different within the settlements. Area Weighted Mean Shape Index (AWMSI) for forest and the entire landscape decreases in Machadinho and increases in Anari during the period of study (Tables 27, 36, 39, and 40). The size and perimeter-to-area relationship of forest patches within the landscapes is certainly affecting the results, as AWMSI increases similarly for all other classes over time. Other quantitative analyses such as the interior-to-edge ratio relating edge and shape metrics could provide an easier intuitive interpretation. Although these relationships were not computed for this study, it is expected that communal reserves in Machadinho tend to increase the interior-to-edge ratio of forest while the narrow elongated forest remnants in Anari tend to lower the ratio for this patch type.

The analysis of shape metrics at the patch level is difficult to interpret, as even radical changes in the shape of some patches may have little effect on the distribution of patch shape values for the class as a whole. For metrics such as area and perimeter this is minimized because they are absolute values without limit and not ratios as the shape metrics are. However, results for the shape index of forest patches indicate a lower shape complexity of forest stands in Anari (Figures 77, 78, and 79). In addition, results for fractal dimension of patches of forest, succession, and production areas behaved as expected and described in previous studies (Frohn 1998). Forest patches tend to have more complex shape than agricultural or successional fields (Figures 80, 81, and 82).

Core-area metrics are the counterpart of edge metrics. They are related to the concept of 'interior habitat,' which is very relevant for a number of species (Patton 1975, Saunders et al. 1991). My decision to choose Total Core Area Index (TCAI) and Mean Core Area Index (MCAI) was to avoid redundancy with patch size, density, and variability metrics, as core area is generally a function of these latter measurements. TCAI and MCAI are relative indices that quantify core area as a percentage of total area (Appendix 2). All these metrics are based on the selection of an edge width, which should be associated with the phenomenon under investigation. As this research is related to processes of LULC change, the choice of an edge width of 90 m was based on potential responses of plants and the environment when subjected to LULC edge effects (Kapos et al. 1997). This decision is somewhat arbitrary, and empirical tests could clarify the effects of changing edge width to core-area metrics values. However, for the comparative purpose of this study, the results are already valuable.

Within the study area, TCAI decreases for all cases (Table 39), suggesting that the landscapes are losing interior habitat as they become more fragmented. Although TCAI is greater in Anari in 1988 because of the large elongated patches of forest, it decreases more slowly in Machadinho including reserves (Table 27). Also, lower values of TCAI in Machadinho when excluding reserves indicate that they play an important role in maintaining interior habitat within the landscape.

MCAI results should be analyzed with caution, as any metric based on first-order statistics. Interesting results were found for MCAI of forest. In Anari, the average of core areas represent 12.5% of the forest class in 1988, but drops to 6.4% in 1998. In Machadinho, MCAI of forest represents just 4.1% of this class in 1988, but increases more than twofold to 8.8% in 1998 (Tables 37 and 40). The meaning of these results can be better interpreted in conjunction with the percentage of the landscape covered by forest (Table 28). Although deforestation is a concurrent process within both landscapes, the architectural design of Machadinho preserves more interior habitat, which relatively increases as the area of forests decrease. This is independent of the large patches of communal reserves and strictly related to the intricate design of Machadinho. Conversely, the initially lower fragmented patches of forest in Anari have a relatively higher percentage of interior habitats in earlier stages of colonization, which drops abruptly as the occupation process takes place.

Diversity metrics brought little new information about landscape pattern and process in Machadinho and Anari. Often criticized for not providing information on the actual composition of a landscape and its elements, these metrics were used solely as a summary about richness and evenness within the study area. Therefore, MSIDI results imply that Machadinho is a less diverse landscape or, in other words, has fewer classes per unit area than Anari. When excluding the reserves, the results for MSIDI in Machadinho are similar to those in Anari, indicating that the diversity within private properties is equivalent in both landscapes. Results for MSIEI suggest that the proportional distribution of area among classes in Machadinho is less equitable than in Anari or in Machadinho excluding reserves (Table 27). Also, MSIEI could be understood as the compliment of dominance (that is, evenness = 1 – dominance). Although diversity metrics do not convey any information about the contribution of each patch type to the final result, analysis of these metrics in conjunction with other metrics (e.g., PLAND) may provide a better perspective about the trends being analyzed. In this sense, lower values of MSIEI in Machadinho reflect a higher dominance of forest within this landscape. By the same token, the ascendant trend for MSIEI in all cases (Table 39) depict the process of deforestation toward landscapes with a more even distribution of patches among forest, succession, and production areas.

The last metric computed for this comparative study was the Interspersion and Juxtaposition Index (IJI). The classic and intuitive way of representing maximum interspersion is by a chessboard, where white cells are evenly distributed in relation to black cells. IJI results indicate that Machadinho's design leads to a more interspersed landscape than Anari's fishbone scheme. They also indicate that the highest interspersion during the period of analysis occurred in 1994 (Table 27). IJI results for forest and production areas follow a similar trend, with lower values in 1988 and 1998, and higher values in 1994. This possibly indicates a threshold in the trajectory of colonization and landscape transformation within the study area. On the other hand, values for succession areas show a decreasing trend in all cases, suggesting that these areas are becoming more isolated within the landscape (Tables 38 and 40). The impact of these spatial relationships to ecological processes is a promising subject for further studies. Particularly, it is important to follow the trends for forest and succession areas and understand the potential impact of patch location within the landscapes to processes such as vegetation recovery or degradation. For these studies, it will be relevant to consider that forest fragmentation in both settlements may affect the propagation of disturbances across the landscapes. For instance, a highly fragmented and interspersed forest, taken as a patch type within the landscape, may be less prone to total destruction by fire as a class in its entirety, although the fragments themselves are more susceptible. For other types of disturbances (logging, for example), larger patches of forest may show a higher resilience than several small fragments. These processes should be investigated and monitored for each landscape through time since they are affected by settlement design, as translated by the metrics discussed in this chapter.

### 5.5.2 - Unresolved problems in spatial data analysis

The search for quantitative methods to analyze and describe the structure of landscapes has become a high priority in landscape ecology (Turner and Gardner 1991, Wiens and Moss 1999). In addition, within a science still dominated by empirical approaches and case studies, the need of standardization is urgent. At least four potential methodological pitfalls should be addressed when analyzing spatial data: the boundary problem, the scale problem, the problem of modifiable units, and the problem of pattern (Burt and Barber 1996).

The boundary problem is related to the extent and location of the boundary of a study area, as well as the placement of the internal boundaries in an areal design (Wiens et al. 1985). The choice of boundaries is particularly important in landscape ecology, because the behavior of landscape metrics is affected by changes in spatial extent (Turner et al. *Effects* 1989). This was one of the first questions when designing the comparative analysis about landscape fragmentation processes in two distinct rural settlement designs in Rondônia. Which limits should be chosen? Where should the subsets be placed?

Should the subsets have the same shape and extent? What will be the effects of boundary placement over landscape, class, and patch metrics?

One option was to choose subsets of exactly the same shape and extent. However, the settlements have completely different designs (Figure 6). Any shape would embrace more than the total area of the settlements or just a part of them. The landscape metrics calculated for these subsets would be strongly affected by segregation or integration problems, not allowing reasonable comparisons between the settlements as a whole. The other option was to digitize the geographic limits of each settlement and calculate the metrics in relation to their extent. Although the shape and extent of the subsets are different, comparative analyses become possible. The boundary problem in this case seems to be avoided, as the unit of analysis is the entire extent of the settlement, which is functionally circumscribed by administrative limits. Besides taking this option for the study, metrics with absolute values, such as number of patches or total area, were avoided to maintain consistency during the comparative approach.

The second problem when analyzing spatial data is related to the grain and is also called the scale problem or the areal aggregation problem (Cao and Lam 1997). In general, spatial aggregation tends to reduce the variation in spatial mosaics (Burt and Barber 1996). This is perhaps one of the most important issues in global change–related research, as scaling up and down is generally suggested (Curran 1989, National Research Council 1998). The qualitative and quantitative changes in measurements across spatial scales differ depending on how scale is defined. Therefore, measurements carried out at different scales may not be comparable. Also, the exact relationship varies across landscapes, creating difficulties in extrapolating from one region to another

(Meentemeyer and Box 1987, Wiens 1989). Diversity metrics, for example, decrease linearly with increasing grain size, while dominance and contagion do not show a linear relationship. Rare classes are lost as grain becomes coarser and dispersed classes are lost more rapidly than clumped ones (Turner et al. *Effects* 1989).

Recognizing that landscape structure varies with scale, landscape ecologists have struggled for scale-invariant measures or indices (Withers and Meentemeyer 1999). The fractal dimension is the most commonly employed such measure. The range of spatial extent over which the fractal dimension is a constant is said to represent the 'scale' of the landscape, or the scale over which the landscape is 'self-similar' (Burrough 1981, Mandelbrot 1983). In other words, over that range of scales, landscape units display similar behavior, appear structurally similar, and are, presumably, affected by the same processes and controls. Other approaches, such as the square-pixel metric, have also been suggested for this purpose when dealing with raster data (Frohn 1998). An alternative measure for shape complexity is the lacunarity index, which is a multi-scaled method for determining the texture associated with patterns of spatial dispersion (e.g., landscape/habitat types or species locations) (Plotnick et al. 1993). Another approach is to identify the scale of discontinuity in landscape structure, or assess the variability or similarity between landscape types or patches. These measures include spatial autocorrelation (Legendre 1993), semivariograms (Curran 1988), and other geostatistical methods (Isaaks and Srivastava 1989, Rossi et al. 1992). A variety of complementary methods have also been developed. Fractal models of landscape patterns have been associated with neutral models of species co-occurrence (Milne 1992). Nested sampling designs have enabled the detection of a wide range of spatial structures, showing the relationships among nested spatial scales (Bellehumeur and Legendre 1998). Hierarchically structured maps have been suggested as a useful tool for studying landscape patterns at different scales (Lavorel et al. 1993). In sum, the need for a 'scale theory' has been defended frequently as an important methodological advance in spatial analysis (Raffy 1994).

For this research in Rondônia the scale problem was minimized using the same grain for both areas of study. The areas are adjacent and belong to the same classified Landsat TM scene. Therefore, comparisons between the areas were possible, as the agroecological processes under investigation (e.g., deforestation, secondary succession, and land conversion to pasture or agriculture) were studied using the same spatial resolution. Potential problems may arise if integration of spatial data produced at other scales is done (e.g., soil maps, topographic features, and so on). In this case, caution should be taken to keep away from biased estimations.

A third potential problem when dealing with spatial data is associated with modifiable units: results vary when areal units are progressively aggregated into fewer and larger units of analysis (Turner et al. *Effects* 1989). This may happen even when using the same grain and extent for the analysis. Burt and Barber (1996) explain how variance may or may not vary depending on the aggregation process. In general, smoothing techniques decrease variance and also increase autocorrelation (Bian 1997). However, the effects of using modified areal units are not always predictable. A rule of thumb to minimize the problem when aggregating data is to join zones with similar attributes (Bian and Butler 1999). This problem is typically recognized when classifying categorical data using hierarchical schemes such as Anderson's LULC system (Anderson et al.1976). Joining distinct classes must be done carefully to avoid an undesirable significant decrease in spatial variance. Important components to consider include the nature of the classification scheme itself, the process of classification output issues, and the phenomenon under investigation (Withers and Meentemeyer 1999).

For this research in Rondônia, image classification was done using the same parameters and spatial-spectral relations for both study areas. Just after obtaining the LULC map for the entire scene, the settlements were separated to run the landscape metrics. This method avoided incomparable approaches between the sites. Difficulties to discriminate some LULC types were solved by analysis of vegetation structure and spectral data, as discussed in Chapter 3. Aggregation of classes for the LULC analysis in Chapter 4 or for the classes used in this chapter was strictly based on functional aspects of each category within the classification system. Although the accuracy achieved using maximum likelihood algorithms was acceptable (Table 13), further approaches may improve the accuracy of LULC classifications for the study area. Spatial autocorrelation studies may support decisions about the classification system and the relationship of neighboring attributes within data elements (Legendre 1993). The use of semivariograms may help the detection of areas with higher chance of showing the modifiable areal unit problem (Curran 1988). Spatial-spectral algorithms may overcome the risk of joining very dissimilar categories (Kettig and Landgrebe 1976, Landgrebe 1980, Woodcock and Strahler 1987).

The pattern in spatial data is another problem for several methods of analysis. Many of them are incapable of assessing the type of pattern present in a spatial distribution (Burt and Barber 1996). Landscape ecologists have also attempted to address this fact when using landscape metrics. In this case, an extra effort has to be made to depict landscape configuration besides describing landscape composition (Li and Reynolds 1993). One way to address the problem is to use second-order statistics methods (e.g., Ripley's K, Moran's I, Geary's c, semivariance, among others). They allow the quantification of small-scale spatial pattern intensity (magnitude, degree) and scale (spatial extent). But, again, these methods were primarily implemented for point data, under the assumption of stationarity. A shortcut to analyze patch data using spatial statistics algorithms is through surface pattern methods, such as join-count spatial correlation coefficients, in which patch centroids can be analyzed with point-pattern methods (Fortin 1999). Perhaps, the landscape metrics more suitable to address pattern in patchy spatial data are contagion and interspersion indices. Contagion measures both patch type interspersion (i.e., the intermixing of units of different patch types) as well as patch dispersion (i.e., the spatial distribution of a patch type) (Li and Reynolds 1993). The interspersion index measures the extent to which patch types are interspersed (i.e., adjacent to each other). The interspersion index is not directly affected by the number, size, contiguity, or dispersion of patches *per se*, as the contagion index is (McGarigal and Marks 1995). Alternative metrics to quantify contagion have also been suggested (Frohn 1998).

For the research in Rondônia, besides the analysis of landscape composition within the two settlement designs, it was important to investigate the variation of spatial arrangement through space and time. Distinct land-use strategies and consequent land-cover spatial outcomes were depicted from this analysis. However, one of the main shortcomings of interspersion metrics, for example, is their capability of analyzing spatial pattern based only on relationships between neighboring zones. More complex spatial relationships involving distant patches are still not implemented.

Last but not least, studies have shown high correlation among particular landscape metrics (e.g., Hargis et al. 1998). Caution should be taken to look for complementary techniques when analyzing spatial data, avoiding redundancy when it is not required. Primarily, besides the constraints of operational limitations, the choice of metrics should be strictly related to the phenomena under investigation. This chapter intended to provide elements for discussion regarding landscape change in the Amazon through the use of quantitative methods of spatial analysis. The next chapter goes beyond the metrics to address the human dimensions of landscape change.